NIOSH MINE FIRE RESEARCH IN THE UNITED STATES

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ABSTRACT

During the time period from 1990-2007, there were 1601 reportable fires that occurred in the U.S. mining industry (an average of 89 fires per year). The leading causes of U.S. mine fires include flame cutting and welding operations, frictional heating and ignitions, electrical shorts, mobile equipment malfunctions, and spontaneous combustion. The National Institute for Occupational Safety and Health (NIOSH) is conducting a program of research addressing metal/nonmetal and coal mine fire prevention, detection, management and suppression. In the metal/nonmetal area, work was focused on technology transfer and training, and research to reduce the number of mobile equipment fires and their hazards. In the coal arena, research is underway to determine the root cause of cutting and welding-related fires and to evaluate the effects of ventilation schemes relative to the spontaneous combustion risk in longwall mines. Relative to fire management, research is ongoing on remote mine seal installation and remote mine fire suppression technologies. Finally, research is continuing to develop comprehensive and usable smoke management techniques and to develop mine fire growth models, propagation, and suppression. This paper presents a summary of some of the mine fire research and provides an overview of the next phase of the NIOSH mine fire research program.

1. INTRODUCTION

Mine operators in the United States were previously required by law to report to the U.S. Mine Safety and Health Administration (MSHA) any unplanned mine fire event that was not extinguished within 30 minutes of discovery (CFR, 2007). Subsequent to the accidents at the Sago and Aracoma Alma mines in January 2006, this regulation was modified to include all unplanned mine fire events that are not extinguished within 10 minutes of discovery (in surface mines and surface areas of underground mines, an unplanned fire not extinguished within 30 minutes of discovery). According to MSHA, in an underground environment, if miners attempt to fight a fire for 30 minutes and are unsuccessful, the fire will probably become uncontrollable. The revised reporting requirement will result in earlier fire-fighting plan activation as miners will notify supervisors more quickly who, in turn, can call in firefighting crews and allow miners to safely escape (Federal Register, 2006).

During the time period from 1990-2007, there were 1601 reportable fires that occurred in the U.S. mining industry (an average of 89 fires per year) (DeRosa, 2008). Figure 1 shows the trend of mine fires for coal and metal and non metal mining operations (note, the upswing in the trend of the data for coal mining operations for the time period 2006-2007 may be a result of the change in the reporting requirements). The leading causes of U.S. mine fires include flame cutting and welding operations, frictional heating and ignitions, electrical shorts, mobile equipment malfunctions, and spontaneous combustion (NIOSH, 2009a). The fact that mine fires continue to occur reinforces the importance of recognizing and eliminating the potential hazards and the overall need for improved fire control and suppression technology to ensure the best possible outcome.

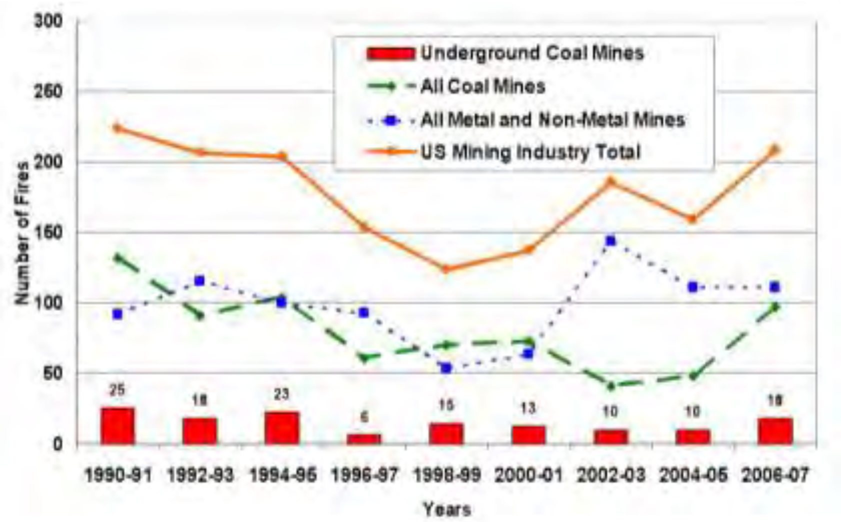

Figure 1: Reported U.S. mine fires from 1990 to 2007 (DeRosa, 2008).

The overarching goal of the NIOSH fire research program is to reduce the risk of mine fires through the development of new or improved strategies and technologies for mine fire prevention, detection, control and suppression. To accomplish this goal, NIOSH is conducting research aimed at ensuring that fire-safe materials are used, that combustibles are properly handled and stored, that mechanical and electrical equipment is properly used and maintained, and that personnel are adequately trained and educated in fire safety practices. NIOSH research is developing rapid and reliable fire sensing systems, guidelines for selecting and using these systems, investigating the principles of fire dynamics and the interaction of gaseous or chemical agents with an expanding flame. In addition, research is addressing the role that ventilation plays in fire control and extinguishment, and how different fire and smoke mechanisms can impact these interrelationships (NIOSH, 2009b).

2. NIOSH MINE FIRE RESEARCH

Current NIOSH research is focused on understanding and controlling spontaneous combustion, the causes of flame cutting and welding fires and injuries, the effects of ventilation on conveyor belt fire suppression systems and remote methods for addressing coal mine fires. The goal of this work is to reduce the number of fires and to improve mine fire control and suppression technology to ensure the best possible outcome during a mine fire. A report on the status of each program area follows.

2.1Spontaneous Combustion

Spontaneous combustion continues to be a hazard for U.S. underground coal mines, particularly in western U.S. where the coal is generally of lower rank. For the period 1990 – 2006, a total of 25 reported fires for underground coal mines in the U.S. were caused by spontaneous combustion (Yuan and Smith, 2009). Spontaneous combustion occurs when the heat that is produced by the low temperature reaction of coal with atmospheric oxygen is not adequately dissipated through conduction and/or convection, resulting in a net temperature increase in the coal mass. Coal oxidation is an irreversible exothermic reaction and its reaction rate increases with temperature and the increase in temperature leads to higher oxidation rate. If not averted with an appropriate action, this process results in the thermal runaway condition and a fire ensues.

The spontaneous heating of coal often occurs in a gob area and may not be easily detected. The risk of an explosion ignited by a spontaneous combustion fire is also present in those mines with appreciable levels of accumulated methane gas. In fact, three of the mine fires mentioned above also resulted in subsequent methane gas explosions. The incidence of such fires and the associated explosion hazard is expected to increase with the projected increased mining of lower rank coals, deeper mines with more methane gas, and the growth in the size of longwall panels.

A computer model has been developed from existing computational fluid dynamic (commonly called “CFD”) codes to describe the ventilation pathways through the immediate gob. CFD is a sophisticated computationally-based design and analysis technique that enables a user to simulate flows of gases and liquids, heat and mass transfer, multiphase physics, chemical reaction, and fluid-structure interaction through computer modeling. Using CFD, the user builds a 'virtual prototype' of the system or device and then applies real-world physics and chemistry to the model to generate images and data, which predict the performance of that design (Fluent, 2009).

In order to reduce the fire hazard from spontaneous combustion of coal in gob areas, NIOSH has conducted a series of computational fluid dynamics (CFD) simulations using coal kinetic data from the former U.S. Bureau of Mines laboratory-scale experimental results (Smith and Lazzara, 1987). Previous CFD models were developed to simulate the spontaneous heating of coals in a two-panel gob area using a bleeder ventilation system with a stationary longwall face (Yuan and Smith, 2007). Parametric studies were then conducted to examine the effects of coal's activation energy, coal surface area, heat of reaction, different ventilation conditions and gob permeability distributions on the spontaneous heating process (Yuan and Smith, 2008). CFD simulations were also conducted to model the spontaneous heating in longwall gob area using a bleederless ventilation system with a stationary longwall face (Smith and Yuan, 2008). Finally, CFD modeling of the effect of longwall face advance on the spontaneous heating of coals in a two-panel gob area using a bleeder ventilation system has been completed (figure 2) (Yuan and Smith, 2009). The results of this work will be used to assist in the design of ventilation systems where spontaneous combustion risk is high.

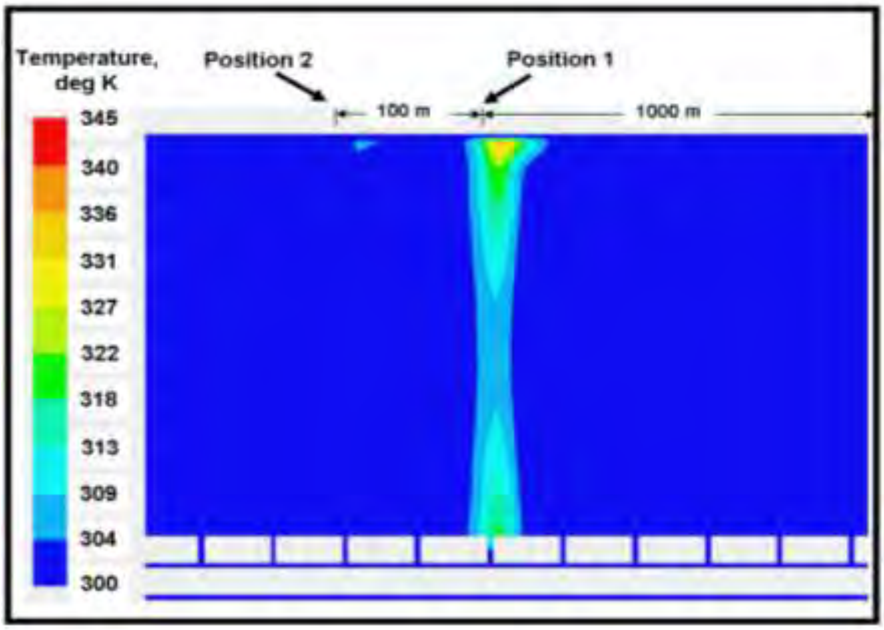

Figure 2. Example plot of the temperature distribution (deg K) from CFD model with the longwall face at location No. 2 for 5 days (Yuan and Smith, 2009).

2.2 Flame Cutting and Welding

To determine the causes of the fires and injuries caused by flame cutting or welding operations, accident investigation reports were scrutinized, workers were interviewed, and flame cutting and welding operations at several underground coal mines were observed. The data from these investigations was analyzed and the following root causes of fires or explosions from flame cutting and welding operations in underground U.S. coal mines were identified (Monaghan, 2009).

- Failure to effectively check for methane gas.
- Failure to adequately inspect for fire during and after cutting or welding operation.
- Proper inspection of tools and equipment prior to starting the task was not sufficiently completed.
- Failure to remove combustible materials such as grease, oil, hydraulic fluid and, coal dust from the item to be cut or welded.
- Ensuring sufficient ventilation air at the work site.
- Failure to provide adequate training for the person performing the flame cutting or welding operation.

Promising direct interventions to prevent the root causes of flame cutting and welding fires were identified and evaluated in field tests at operating underground coal mines. Existing training methods and procedures were examined and improvements to these methods and procedures were developed and tested in the field.

2.3 Conveyor Belt Fire Suppression

NIOSH, in partnership with the Mine Safety and Health Administration (MSHA), initiated a test program to determine the effectiveness of fire suppression systems on conveyor belt fires in entries with high-velocity air flow (figure 3). Full-scale experiments evaluated the effectiveness of dry powder chemical suppression systems, water sprinkler systems, and water deluge systems in simulated conveyor belt entry at air velocities of 2.5 to 2.8 m/sec (500 to 550 ft/min) and 6.7 to7.6 m/sec (1,350 to 1,500 ft/min) (Rowland III *et al*, 2009). The data from this work will be used to develop guidelines for the installation and use of fire suppression systems in ventilated belt entries. In late 2007, the scope of this research was modified to include the recommendations made by the Technical Study Panel on the utilization of belt air and the composition and fire retardant properties of belt materials in underground coal mining (Mutmansky *et al*, 2007). NIOSH will conduct research to improve fire suppression systems by evaluating new technologies, new nozzle designs, spacing of nozzles, and system activation temperature. Tests on two water-based suppression systems, a water sprinkle and a deluge type water spray, show that the systems were able to suppress test fires. However, the amount of water needed to suppress the fire to the point where a miner could walk up to extinguish any smoldering belt was greater than the current MSHA regulations require. MSHA regulations only require 10 minutes of water supply to the suppression system. In this test set-up, it is unlikely that either of these systems would have suppressed the fire had the water been turned off to the system after 10 minutes, based on visual observation. Test on two dry chemical suppression systems provided mixed results as one system did not extinguish the fire in either air-velocity condition. This system uses a nominal weight of 300 lb of dry chemical agent and 40 nozzles to protect 50 ft of fire resistant conveyor belt. The primary failure mechanism was damage to the hoses from the fire prior to system activation. Several of the nozzles in system A did not discharge any dry chemical agent because the hoses leading to the nozzles were severely damaged by the fire. The dry chemical fire suppression system B performed well at the lower air velocity; however, at the higher air velocity mixed results were obtained (Rowland III *et al*, 2009).

In a related study, conveyor belt, typical of the type used in metal/nonmetal mines, where no mandatory fire resistance standards apply, were evaluated for their fire resistance. The results clearly showed the hazards of using non-approved conveyor belting and demonstrated that the use of approved conveyor belting can significantly reduce potential fire hazards.

Figure 3: Conveyor belt fire suppression system set-up at the NIOSH Fire Suppression Facility (Rowland III *et al*, 2009).

2.4 Remote Methods for Addressing Coal Mine Fires

The ability to remotely address coal mine fires can reduce worker exposure to hazardous situations. The objective of this work is to evaluate, improve or modify remote fire-fighting technologies, including remotely installed mine seals (ventilation barriers), and fire control and suppression technology. This research effort is being conducted with active industry participation and with the input from MSHA technical specialists serving as research partners.

Full-scale remote mine seal installation experiments have been conducted to evaluate cement-based and rigid-foam based materials at the NIOSH Lake Lynn Experimental Mine (LLEM). The LLEM (located approximately 97 km (60 mi) southeast of Pittsburgh, Pennsylvania) is a world-class, highly sophisticated underground facility where large-scale explosion trials and mine fire research is conducted. This work has resulted in new understandings of the limitations of the technology and development of novel downhole tools to facilitate accurate placement of mine seal materials.

Preliminary research on nitrogen gas-enhanced foam (foam resulting from commingling of nitrogen gas, water and a specialized foam concentrate) shows that foam can be stable in the mine opening and can accumulate and flow through mine workings (figure 4) (Smith *et al*, 2005).

2.5 Testing of Temporary Ventilation Control Devices

NIOSH in partnership with Strata Products tested the sealing capability of Ventstop®™[1] as part of an ongoing program to evaluate promising technologies. Ventstop®™ is a multi-purpose, inflatable device produced by Minvent Solutions and is available world wide for use in the metal and nonmetal mining industry. Ventstop®™ is used as an emergency seal (temporary ventilation control device), controlling ventilation in breakthrough situations, radiation dust, thermal heating return vent, blast fumes, fires, pass plugs and shaft sealing system. The device is reusable and can be placed in horizontal and vertical mine voids. Ventstop®™ was introduced into the Australian Coal Industry in 2005.

Deployment, multi-day inflation and air leakage tests were conducted at the LLEM to determine the capability and limitations of Ventstop®™ in a simulated coal mine setting (figure 5) (Trevits, 2009). During the tests, Ventstop®™ was also subjected to low level forces of a nearby methane gas ignition. Testing showed that Ventstop®™ could be quickly deployed by two persons in approximately 7.5 minutes (to install the unit from the carry bag to full inflation in the mine opening and 5.5 minutes to inflate the unit only). Deflation of the unit, folding and replacement into the carry bag took about 15 minutes (11 minutes to deflate the unit only). Air leakage testing showed that the unit could provide an effective temporary mine seal that could be further enhanced through the application of a polyurethane (PUR) sealant. Inflation of the unit for extended periods of time (24 hrs or greater) is possible through the use of a pressure demand control system. In these tests, mine ventilation air leakage rates were between 1.6 and 5.0 m^3/min (55 and 175 ft^3/min) depending on inflation pressure without the use of PUR sealant. When PUR sealant was applied to the unit, air leakage rates were substantially reduced by 85%. Pre- and post-methane gas ignition tests show that air leakage past the Ventstop®™ unit was not affected by the forces of the pressure pulses from the ignition.

[1] Mention of a specific product or trade name does not imply endorsement by NIOSH.

Figure 4: Compressed air gas-enhanced foam accumulating behind and moving through crib block sets at the LLEM (Smith *et al*, 2005).

Figure 5. Underground testing of an inflatable temporary ventilation control device (Trevits et al, 2009).

It is thought that Ventstop®™ could be used by the US coal mining industry to temporarily close an underground mine area in response to a fire or spontaneous combustion heating event, to temporarily redirect mine ventilation during longwall equipment moves or during stopping construction.

3.0 FUTURE RESEARCH

Planned work under the NIOSH mine fire research program will continue the spontaneous combustion modeling effort. The work will focus on western U.S. coal mines by simulating longwall gob areas and collaborating with western U.S. coal mine operators to collect spontaneous combustion data to calibrate the CFD model. CFD modeling will also be used to investigate nitrogen gas injection strategies to prevent the spontaneous heating in coal mines using bleederless ventilation systems and to suppress the spontaneous heating in coal mines using bleeder ventilation systems. It is hoped that this work will result in improved understanding of the conditions that lead to heating events and should also result in new ventilation practices and technologies to reduce the risk and number of fires.

The conveyor belt fire suppression program will focus on the reduction of the hazards of underground coal mine fires, particularly in conveyor belt entries, by applying recent technological advances in the areas of fire-resistant and fireproof belt materials, belt fire suppression systems, atmospheric monitoring systems, and computer codes for predicting and assessing in real-time the impact of fire on the mine ventilation system. In addition, the work will include an overall evaluation of the flammability of conveyor belts, modeling of conveyor belts fires, modeling of contaminant spread, fire risk assessment, and training and maintenance. It is expected that the research output from this work will substantially reduce the number of fires and injuries/fatalities due to conveyor belt fires and will significantly improve the level of fire safety in mines.

4.0 SUMMARY

Mine fires represent one of the greatest threats to those working in the underground mine environment. NIOSH mine fire research is addressing a wide spectrum of problem areas facing the U.S. mining industry. The intent of the research is to provide the mine operator and miners with an understanding of the conditions that could lead to a fire, the capability to detect unusual heating or fire conditions, and the technology to suppress and extinguish a fire to ensure the best outcome possible. Research papers that discuss much of the work presented in this article are available through the NIOSH mining website. A discussion and description of the NIOSH Mining Research Program and copies of all NIOSH published mining research work can be obtained by browsing to http://www.cdc.gov/niosh/mining.

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